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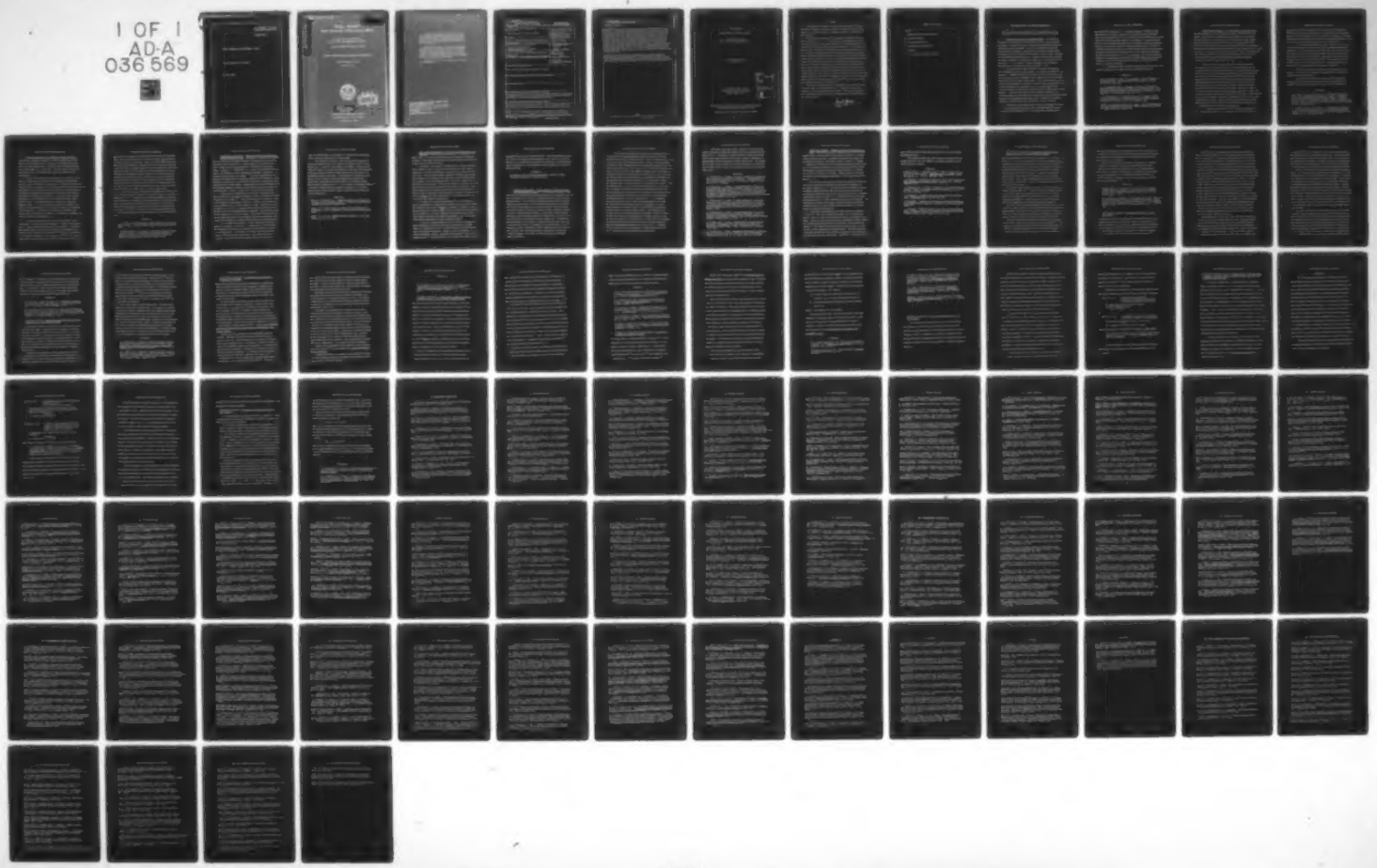

BASIC RESEARCH IN ELECTRONICS (JSEP)

TEXAS UNIVERSITY AT AUSTIN

15 MAY 1976

FINAL REPORT
Basic Research in Electronics (JSEP)

For the Five—Year Period
April 1, 1971 through March 31, 1976

Contract AFOSR F44620—71—C—0091

JOINT SERVICES ELECTRONICS PROGRAM

Technical Report No. 186

May 15, 1976

ELECTRONICS RESEARCH CENTER
The University of Texas at Austin
Austin, Texas 78712

The Electronics Research Center at The University of Texas at Austin constitutes interdisciplinary laboratories in which graduate faculty members and graduate candidates from numerous academic disciplines conduct research. The disciplines represented in this final report include solid state electronics, information systems, plasma and quantum electronics, bio-medical electronics and acoustics and radio sciences.

The research summarized in this final report was supported in part by the Department of Defense's JOINT SERVICES ELECTRONICS PROGRAM (U.S. Army, U.S. Navy, and the U.S. Air Force) through the Research Contract AFOSR F44620-71-C-0091. This program is monitored by the Department of Defense's JSEP Technical Advisory Committee consisting of representatives from the U.S. Army Electronics Command, U.S. Army Research Office, Office of Naval Research and the U.S. Air Force Office of Scientific Research.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR - TR - 77 - 0118	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) "Basic Research in Electronics (JSEP)"		5. TYPE OF REPORT & PERIOD COVERED Final Report, April 1, 1971 - March 31, 1976
		6. PERFORMING ORG. REPORT NUMBER Technical Report #186
7. AUTHOR(s) Arwin A. Dougal (Director), and other faculty and graduate research staff members of the Electronics Research Center		8. CONTRACT OR GRANT NUMBER(s) Research Contract F44620-71-C-0091
9. PERFORMING ORGANIZATION NAME AND ADDRESS Electronics Research Center The University of Texas at Austin Austin, Texas 78712		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 4751 681306
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Air Force Office of Scientific Research (NE) Building #410 Bolling Air Force Base, District of Columbia 20332		12. REPORT DATE May 15, 1976
		13. NUMBER OF PAGES 86
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SOLID STATE ELECTRONICS, INFORMATION SYSTEMS, ELECTRONIC COMPUTERS, ELECTRONIC CONTROLS, PLASMA AND QUANTUM ELECTRONICS, BIOMEDICAL ELECTRONICS, AND ACOUSTICS AND RADIO SCIENCES

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Basic research in electronics was pursued in the areas of solid state electronics, information systems, electronic computers, electronic controls, plasma and quantum electronics, biomedical electronics, and acoustics and radio sciences.

Sixteen of the most significant research accomplishments are summarized in Chapter I, pp. 1 - 36. These significant accomplishments include parallel processing in computer architecture, self-induced transparency at 10.6 microns

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ABSTRACT, continued:

in molecular gases, laser raman spectra of van der waals complexes in argon, measured and predicted laser-induced temperature rise in the eye, new solid state electronic devices utilizing thermodynamic transitions, spectra analysis of plasma fluctuation data using digital computers, feedback control of linear systems with delay, new polarity-dependent memory switching in devices in SnSe and $SnSe_2$ crystals, self-induced transparency with CO_2 laser pulses, picture processing using one-dimensional implementations of discrete planar filters, large refractive index change by photolysis in lead iodide, elastic electron scattering amplitudes for interpretation of low energy electron diffraction data, proving and strong verification of electronic computer software programs, third harmonic generation in SF_6 at 10.6 microns, magnetotelluric and dipole-dipole soundings in Northern Wisconsin, and distribution free performance bonds in error estimation.

Additional significant research accomplishments are listed in Chapters II Journal Articles, III Published Abstracts, IV Conference Proceedings, V Reports, and VI Full-Length Technical Reports. Sixty-seven full-length technical reports were published and distributed during the five years of activity on this Contract.

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ABSTRACT

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Sixteen of the most significant research accomplishments are summarized in Chapter I, pp. 1 - 36. These significant accomplishments include parallel processing in computer architecture, self-induced transparency at 10.6 microns in molecular gases, laser raman spectra of van der waals complexes in argon, measured and predicted laser-induced temperature rise in the eye, new solid state electronic devices utilizing thermodynamic transitions, spectra analysis of plasma fluctuation data using digital computers, feedback control of linear systems with delay, new polarity-dependent memory switching in devices in SnSe and $SnSe_2$ crystals, self-induced transparency with CO_2 laser pulses, picture processing using one-dimensional implementations of discrete planar filters, large refractive index change by photolysis in lead iodide, elastic electron scattering amplitudes for interpretation of low energy electron diffraction data, proving and strong verification of electronic computer software programs, third harmonic generation in SF_6 at 10.6 microns, magneto-telluric and dipole-dipole soundings in Northern Wisconsin, and distribution free performance bonds in error estimation.

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Arwin A. Dougal
Director

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I. SIGNIFICANT ACCOMPLISHMENTS

More than fifteen of the most significant accomplishments from our Basic Research in Electronics (JSEP) are summarized in this chapter.

A. Parallel Processing in Computer Architecture. The problem of decomposing a large computer program (task) into many small concurrently executable or "parallel processable" segments has attracted both theoretical and practical interest and effort. Parallel processability permits faster execution times of programs on multi-processing computing systems beyond the speeds imposed by technological limitations, as well as other advantages, such as better utilization of resources. Attention has been given to parallel processing in computer architecture by Professor C. V. Ramamoorthy, Mario J. Gonzalez, Jr., K. M. Chandy, and other colleagues of the Electronics Research Center, The University of Texas at Austin. [1-4]

Computer program (task) suitability for parallel processing has been investigated and the results reported [1] by Professor Ramamoorthy and Gonzalez. A FORTRAN parallel task recognizer was developed which accepts source programs written in FORTRAN and then generates a set of tables which communicate to the operating program tasks. The recognizer has been used to analyze several programs in an attempt to determine what characteristics render a program suitable for parallel processing. In an earlier paper entitled, "A Survey of Techniques for Recognizing Parallel Processable Streams in Computer Programs," presented at the 1969 Fall Joint Computer Conference, [2] a general technique was developed that recognized the various parallel processable segments in a sequentially coded program (task) and defined an orderly way of parallel processing these various segments in a multi-processor.

Recently, Professor Ramamoorthy, Chandy, and Gonzalez described [3] a set of techniques that could be used to optimally schedule a sequence of interrelated computational tasks on a multi-processor computer system.

(I. SIGNIFICANT ACCOMPLISHMENTS)

This study had two objectives: 1) to develop theorems on optimal parallel scheduling and to write on the basis of these theorems a program that determines the optimal schedule; and, 2) to evaluate a near-optimal heuristic using the results of the optimal parallel schedule as a "yardstick." It should be stated that the optimal scheduling algorithm was not intended for real-time application; however, it is useful as a means of evaluating heuristics and as a design aid in dedicated systems that process a few basic programs that can be pre-analyzed. An optimal algorithm for basic scheduling of a set of computer tasks has been developed and is presented in Ref. 3. Two heuristics and a random sequencing algorithm were experimentally evaluated by Professor Ramamoorthy, Chandy, and Gonzalez. Their results indicate that the heuristics are accurate and fast enough for real-time application.

Parallel processing in computer architecture, including associative ensemble processing, has applications to large parallel data bases.

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B. Self-Induced Transparency at 10.6 Microns in Molecular Gases. The optical phenomenon of self-induced transparency (SIT) occurs when an intense, short light pulse travelling through an otherwise strong absorber encounters little or no actual absorption. The onset of the highly nonlinear optical process giving such a result occurs when the light pulse width is shorter than the relaxation time of the medium through which it is propagating, provided that the electric field intensity is large enough. Professor W. M. Clark, Jr. and C. D. David, Jr. of the Electronics Research Center, The University of Texas at Austin reported [1] on self-induced transparency at 10 microns in a simple molecular absorber at the VII International Quantum Electronics Conference, Montreal, Canada, May 8-11, 1972.

With the advent of various high-power Q-switched and mode-locked laser systems, practical interest in self-induced transparency and its related effects has been kindled. This is because the potential usefulness of these laser systems to transmit pulse information and radar signals long distances in the atmosphere could be helped or hindered by various self-induced transparency effects; for instance, for certain laser pulses theory predicts that the laser pulse will break up into two or more pulses which would be deleterious to both information and radar applications. Another instance where self-induced transparency could be used to great advantage is in the case of the high-power CO_2 gas dynamic laser (GDL). In this case, the resonant absorption of the laser output by the natural CO_2 in the atmosphere causes "thermal blooming" where the propagating medium (e.g. air) acts like a negative lens. However, pulses under certain conditions for ideal self-induced transparency will not expand, and the high-power radiation from a laser can be delivered to the target in a narrow beam.

A goal of this research project [2] was an experimental study of self-induced transparency in a more general case than has been previously

reported plus the specific study of the use of self-induced transparency effects to off-set the thermal blooming of CO_2 laser light in the atmosphere. Because of the small absorption by CO_2 gas of the laser radiation, an absorber more suitable for the laboratory was chosen; namely ammonia gas which is tuned to exact resonance with the laser frequency by an electric field.

A 1.5 meter linear discharge gas laser, He-N_2-CO_2 or N_2O, was employed by Professor Clark and David in their self-induced transparency experiments. [1,2] The laser was Q-switched with a rotating mirror, and the resulting pulse was electro-optically shuttered using a CdTe crystal--the result was a high peak power short pulse approximately one-half to several kilowatts depending on the laser line selected. The electro-optic shutter produced a pulse of less than 20-ns duration. The optical radiation was detected by a Au:Ge photodetector and sampling oscilloscope.

The absorption cell contained one-meter electrodes separated by 5mm. At 10 mTorr, electric fields of approximately 20 kV/cm could be applied without gas breakdown.

Self-induced transparency phenomena, including nonlinear transmission, pulse delay, and pulse breakup, have been observed and reported [1,2] for ammonia transitions using CO_2 and N_2O laser lines.

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2. W. M. Clark, Jr. and C. D. David, Jr., "Self-Induced Transparency at 10.6 μ Using Simple Molecular Gases," Texas Biannual of Electronics Research, No. 15, Electronics Research Center, The University of Texas at Austin, pp. 118-123, May 15, 1972.

C. Laser Raman Spectra of Van der Waals Complexes in Argon. In a journal article accepted for publication in Physical Review Letters (1972), Professor Lothar Frommhold and C. E. Morgan of the Electronics Research Center, The University of Texas at Austin report the first Raman Spectra of Van der Waals dimers in the noble gases. This basic atomic and molecular physics data will be useful in high-power laser and nonlinear process investigations.

Van der Waals dimers have long been known to exist in the noble gases. The difficult task of detection and measurement of their spectra, however, has been achieved only in recent years. Dimers in the noble gases have been detected and reported in mass spectra and in vacuum ultraviolet spectra. Raman Spectra of the noble gases have been measured by a number of workers but apparently scattering from collision pairs only (the so-called collision-induced light scattering) has been observed. In all of the earlier reported investigations, either the liquid state or high density gas were needed to record the spectra. At such high densities the dimers are perturbed by neighboring atoms. In a recently published theoretical investigation it was pointed out that dimer spectra are more likely to be observed at low densities and low temperatures. In addition, because of the comparitively small frequency shift of dimer spectra, reduction of stray light in the Rayleigh wings may be necessary for their observation.

Using a six-watt argon ion laser (5145 Å and 4880 Å, a triple monochromator, and photon counting techniques, Professor Lothar Frommhold and C. E. Morgan measured the Raman spectra, polarization, and intensity of light scattered from gaseous argon. [1,2] The pressure dependence of the intensity of light scattered was investigated over the range 1 to 4 atmospheres and the temperature dependence over the range 100 °K to 300 °K. A ninety-degree scattering geometry was used in which the electric vector of the laser

beam was at right angles to the optical axis of the entrance slit collection optics. The laser was focused to a narrow beam in the sample cell which was located inside a vaccum dewar. Both the 5145 Å and 4880 Å laser lines were used in this work with the same results. Pressure was measured with an accurate mercury manometer having a range of 0 to 3200 Torr. Temperature was measured with an iron-constantan thermocouple made from 0.001 inch diameter wire and placed inside the sample cell 2 mm from the laser beam. A tungsten ribbon filament lamp with calibration traceable to the National Bureau of Standards was used for intensity calibration of the spectrometer over the frequency and intensity ranges of interest. Ultrahigh purity argon was used in this work. After Raman spectra were taken, mass spectra were run on the argon in the sample cell as a check on sample purity.

Raman spectra for argon obtained at temperatures of 300°K, 152 °K, and 103 °K with the 4880 Å laser line, and an argon pressure of 2140 Torr are presented in Ref. 1. A continuous band structure resembling an unresolved pure rotation band was observed in the Raman spectrum of high purity gaseous argon. The wavelength, corresponding to the peak of the band structure, shifts with temperature in agreement with the theoretical shift of the pure rotation band of a diatomic molecule. The value of the rotational constant is in good agreement with that derived from second virial coefficient data for argon.

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2. L. W. Frommhold and C. E. Morgan, "Raman Spectra of Van der Waals Complexes in Argon," Texas Biannual of Electronics Research, No. 15, Electronics Research, No. 15, Electronics Research Center, The University of Texas at Austin, pp. 86-87, May 15, 1972.

D. BIOMEDICAL ELECTRONICS: Measured and Predicted Laser-Induced Temperature Rise in the Eye. Safe exposure levels for laser and xenon flash sources were successfully determined by experimentally measuring the intensity at which damage occurs. Retinal damage caused by high intensity light from these sources is generally due to a temperature increase in the fundus. Professor A. J. Welch and Dr. C. P. Cain of the Electronics Research Center, The University of Texas at Austin have developed a technique for measuring the temperature of the fundus. (1) Accurate measurements of temperature in the eye provide the necessary information for establishing a reliable temperature model for the eye and provide explicit data for relating light source characteristics to retinal damage. Computed safety criteria eliminates the need for the present exhaustive animal burn tests that are conducted to specify the possible hazards of military systems that use intense laser light sources.

Measurements of temperature in the eye were successfully made using a thermocouple specifically designed for accurate measurement of transient temperatures in a biomedia. (2) A one millimeter quartz rod is drawn in a flame to a tip diameter of approximately 15 microns. On this, a layer of nickel is vacuum deposited on one side and copper on the other, with the two metals overlapping in the tip end. A polymer coating is vacuum deposited between the films and over the completed probe for insulation. The probe tip diameters normally range between 10 and 30 microns. The effective volumetric specific heat and thermoconductivity of the completed probes are approximately those of quartz along which are not greatly different of those of a typical biomedia.

In the experimental research, a surgical procedure exposed the posterior of the rabbit or monkey eye. A thermocouple is inserted through the sclera and with the aid of an ultrasonic dental drill which is mounted on a micromanipulator. The insertion is continued until the tip of probe is observed in the retina with a fundus camera. The depth of the probe may be varied in 3 micron steps and the distance between the probe and the

center of the light image may be varied in 10 microns steps by adjustment of the animal holder with respect to the laser beam.

Upon irradiation by a laser, with the thermocouple positioned in the pigment epithelium and in the center of the irradiance image, the temperature rise is recorded for step changes in irradiance. Movement of the image with respect to the probe and variations of the depth of the temperature probe permit repeated temperature measurements and the construction of temperature profiles for the fundus. The temperature-time histories of the fundus are then compared to predicted temperatures computed from a mathematical model which has been developed for the Defense Nuclear Agency (formerly DASA) and the U. S. Air Force School of Aerospace Medicine.[3] A comparison of experimental and computed temperatures for the rabbit fundus indicates that the model provides a reasonably accurate prediction of retinal temperature.

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E. SOLID STATE ELECTRONICS: New Devices Utilizing Thermodynamic Transitions. Significant progress was made by Professors R. M. Walser and R. W. Bene' in the past year toward understanding the dynamic properties of parameters near phase transitions and exploiting these parameter variations in new electronic devices.

In particular, the variation of thermal profiles in the semiconductor-metal, vanadium dioxide, (VO_2) with various conditions of bias, ambient temperature, and modulated radiation were observed using scanning infrared microscopy. The small-signal voltage response to modulated laser radiation under constant current conditions was measured on some of our initial films of VO_2 biased in the thermal filament regime. The output response was on the order of 50 volts per watt with the output dropping to one-half near 20 KHz. These initial measurements indicate that still thinner films may give useful infrared detection up to the MHz range and may be well suited to infrared detecting arrays, particularly since the detection properties of an element tend to become better as the element gets smaller. A full account of this work is currently being prepared for publication.

In related work, we have demonstrated that a new mechanism may exceed in importance the magnetostrictive effect for use in acoustic detectors. This mechanism which used a combination of pressure to thermal conversion and the pyromagnetic coefficient ($\frac{dM}{dT}$) has been demonstrated using gadolinium with the response on the order of magnitude of magnetostriction in nickel. Other materials (less easily fabricated than gadolinium, Gd,) are predicted to have acoustic responses two orders of magnitude higher.

Our work on infrared radiation detectors utilizing the pyromagnetic effect near magnetic transitions has turned up mechanisms in materials which are of importance both for use in practical detectors and for shedding light on the behavior of materials. Studies on the spin reorientation of ytterbium orthoferrite ($YbFeO_3$), which have been accepted for publication in Physical Review,[1] show the existence of two second order phase transitions

associated with the spin reorientation process. The low temperature response was a factor of 300 greater than the response in Gd (a near state-of-the-art detector), an observation which suggests the practicality of a mixed samarium-yttrium orthoferrite with a room temperature gain reorientation as an infrared detection material.

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F. PHYSICAL ELECTRONICS: Spectral Analysis of Plasma Fluctuation Data Using Digital Computers. From an experimental point of view, the problem of analyzing fluctuation data associated with instabilities and turbulence in plasmas may be viewed as a problem in analyzing random data from physical systems. To the extent the fluctuation data are random, one must depend upon measurements of various statistical quantities to yield insight into the nature and physical origin of the fluctuations. Professor Edward J. Powers and Donald E. Smith of the University of Texas' Electronics Research Center have investigated the feasibility of using digital spectral analysis techniques to study and interpret plasma fluctuation data. As outlined in ref. 1, such an approach is quite powerful in that it enables one to simultaneously measure frequency ω, wave number k, phase velocity and coherence of each of several modes present in the transition to the turbulent state. Such information on ω and k is particularly useful in identifying the waves from their phase velocity (ω/k), and in experimentally checking the selection rules, or resonance conditions, associated with various mode-mode interactions leading to turbulence.

In an attempt to determine the merits of such an approach, Powers and Smith utilized spectral analysis to trace the evolution of drift wave turbulence from a single coherent drift-wave, to a multi-mode spectrum, through a non-linear mode-mode interaction regime to, finally, a turbulent spectrum. The results of this investigation have been reported at national [2,3] and international conferences [4,5], and in refs, 1 and 6. In the mode-mode interaction regime, they were able to experimentally demonstrate that in many cases the resonance conditions (or selection rules) involving ω and k of the interacting waves are satisfied. Without the aid of spectral analysis techniques, such measurements would be extremely difficult, if not impossible, to make. In the turbulent regime, the power spectra were observed to fall off as ω^{-n}, where the spectral index $n = 5.0 \pm 0.4$ is in agreement with theory. At the same time, the phase of the cross-power spectrum indicated that k and ω were linearly related; this information on k (ω) is necessary to relate experimental power spectra measured as a function of frequency ω to theoretical power spectra expressed as a function of wave number k . The constant of proportionality between k and ω is the electron diamagnetic drift speed. In fact, Powers and Smith observed that from the appearance of a single coherent mode at low magnetic fields, to the simultaneous appearance of several modes at intermediate magnetic fields, to the development of a turbulent spectrum at high magnetic fields, all phase velocities of interest are very close to the electron diamagnetic drift speed in absolute value, direction and dependence on magnetic field. For this reason, they describe the observed turbulence as drift wave turbulence. Spectral analysis of other interesting plasma phenomena may be found in ref. 1. Examples include: evolution of multi-mode spectra, turbulent destruction of drift-waves, and resonant and nonresonant harmonic generation.

(I. SIGNIFICANT ACCOMPLISHMENTS)

On the basis of the above study, it appears that digital spectral analysis techniques possess great potential as a new and powerful plasma diagnostic tool. In addition to the basic studies of the nature described above, digital spectral analysis should also be useful in furthering our understanding of random processes in plasma-based devices. For example, such an approach should prove to be fruitful in examining the relationship between output noise in a gas laser and plasma fluctuations in the gas discharge itself.

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G. ELECTRONIC SYSTEMS: Feedback Control of Linear Systems with Delay. The problem of optimal feedback control of linear systems containing delay is fundamental and has important applications to systems containing transportation lags. Significant findings on analytical as well as computational aspects of time delay systems are achieved. Professor J. K. Aggarwal and other members of the Information Systems Research Laboratory of the Electronics Research Center discovered basic analytical results and developed computational algorithms towards the objective: feedback control of linear systems with time dealy. These significant results have culminated in several important publications [1-4] on various facets of the problem.

The solution to the basic case of the lumped delay where the system is described by differential-difference equations with a quadratic cost functional is presented in [1]. The results include the derivation of partial differential equations describing the cost and control functionals and a computational algorithm for the solution of the derived equations. Additional computational results, as given in [2], reduce the solution of the partial differential equations to ordinary differential equations with parameters. This significant step (because of the ease of numerical solution of ordinary differential equations over that of partial differential equations) is achieved through an applicable transformation.

Two distinct generalizations of the basic problem are presented in [3] and [4]. The case of distributed delay (in [4]) is particularly important in view of the fact that transportation lags are best modeled by such delays. Here the lumped part of the system is described by ordinary differential equations and the distributed part is described by partial differential equations. The lumped as well as distributed parts are subject to control, and both controls contribute to the cost-functional. The derived analytical results and numerical algorithms enable the computation of the control and cost functional, and state of the system. Reference [3] discusses similar

results for the case where the system is described by a set of functional differential equations.

The results discussed above were presented at national and international meetings [5-6] and constitute an important contribution in the feedback control of systems.

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(I. SIGNIFICANT ACCOMPLISHMENTS)

H. SOLID STATE ELECTRONICS: New Polarity-Dependent Memory Switching in Devices with SnSe and $SnSe_2$ Crystals.

Significant accomplishments were made by Professors R. M. Walser, R. W. Bene', and T. H. Courtney in the past year toward understanding polarity-dependent memory switching in devices with SnSe and $SnSe_2$ crystals.[1,2] They obtained two types of low-level (1 volt/1 milliampere) switching with reversed polarity dependence in suitably formed devices in crystalline SnSe and $SnSe_2$ with aluminum contacts. In addition, they obtained a high-level (100 volts/10 milliampere) polarized memory switching in either material. The low-level switching appears to involve an electronic process, while the high-level switching is associated with an electrothermally driven mass transport.

The SnSe and $SnSe_2$ crystals were grown by an iodine vapor transport method in a closed Vycor tube. Crystals of good optical quality and areas of 0.2 cm^2 were obtained with thicknesses ranging from 10 to 100 μm. Crystal structure and composition were verified by X-ray and electron microprobe measurements. In most of our work, aluminum electrodes were vacuum deposited on crystals approximately 100 μm thick.

Low-level polarity-dependent memory switching has been previously observed by other researchers in GaAs Schottky diodes and several heterojunction diodes, including Ge-CdS, Ge-ZnSe, GaAs-ZnSe, GaP-Ge, and GaP-Si. The salient features of the low-level switching in our devices appear to correspond closely with those observed for their devices.

Since our investigation of switching in SnSe and $SnSe_2$ is still at an early stage, some of the mechanisms are purely speculative.[1] We are presently conducting detailed electrical and physical experiments to enable us to model the process in this system and related materials. The rectifying and memory property of the device are still not understood.

Several possible explanations being considered involve: 1) formation of a p-n heterojunction following successive forming current pulses; 2) interface state semiconductor junctions; and 3) both heterojunction and Schottky barrier formed by mass transport.

Our recent investigations of polarity-dependent memory switching in devices with crystalline n-SnSe, and p-SnSe produced low-level switching characteristics with thresholds of about 1 volt/milliampere and high-level switching characteristics with thresholds of approximately 100 volts/10 milliamperes. With appropriate forming processes, the polarity of the low-level memory switching can be reversed in the same device of either material. [1]

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I. QUANTUM ELECTRONICS: Self-Induced Transparency with CO_2 Laser Pulses.

The effects of self-induced transparency on the propagation of CO_2 laser radiation in materials (gases, liquids, solids) is of interest because of possible applications of CO_2 lasers to communications and laser-produced plasma experiments. Professor W. M. Clark, Jr. observed self-induced transparency effects (namely, pulse delay and nonlinear transmission) at two CO_2 laser lines with a Stark-tuned ammonia gas absorber. [1,2]

(I. SIGNIFICANT ACCOMPLISHMENTS)

In Professor Clark's experiments, the longitudinal discharge CO_2 laser used was Q-switched by a rotating mirror driven by a synchronous motor. A blazed-grating, whose first-order efficiency was nearly 100%, was used to select the desired laser, rotational transition, and a 7-meter radius-of-curvature 90% reflecting Germanium mirror was used as the output laser beam coupler. The Q-switched TEM_{oo} output laser beam power was varied by changing the synchronous motor speed that drove the rotating mirror. For the R(6), CO_2 laser line the peak power per pulse was 378 watts at 82 Hz, 183 watts at 156 Hz, and 13 watts at 210 Hz. The corresponding laser pulse duration (FWHM) for each case was 276, 240, and 176 nanoseconds. Similar results, but with slightly less output power, could be obtained with the CO_2 laser P(32) line. A simple, well-known molecule that possesses several nondegenerate transitions near the CO_2 laser output beam's wavelength (10.6 μm) is ammonia (NH_3) gas. One of the vibration-rotation transition of the ammonia gas can be "tuned" by use of the Stark effect to exact resonance, without spatial degeneracy, with many CO_2 and N_2O laser lines. Two CO_2 laser-ammonia absorber coincidences that are well suited for self-induced transparency experiments are the asQ(5,3,5) ammonia transition, which is tuned to resonance with the 10.7 μm P(32) CO_2 laser line by a Stark field of 12.3 kV/dm, and the saQ(5,5,5) ammonia transition, resonant with the 10.6 μm R(6) CO_2 laser line in a Stark field of 14.6 kV/cm.

After emerging from the CO_2 laser, the laser beam was focused by a Germanium lens into the Stark, ammonia gas cell. The position of the lens was adjusted so that the Gaussian beam size (distance between e-folding points) at the Stark cell entrance was less than the parallel plate electrode separation, while the minimum beam "waist" was positioned near the mid-point of the cell length. A portion of the laser beam was deflected from a NaCl flat to act as a trigger signal. The Stark, ammonia

gas cell consisted of two 3 meter long, 1/4-inch thick parallel aluminum electrodes inserted in a 2-inch diameter glass tube. The electrodes were separated by glass cylinders 5 mm in length. The maximum single-pass unsaturated linear absorption for this Stark cell gave a transmitted power ratio of exp(-1.5) and corresponded to a maximum ammonia gas pressure of 8 mTorr before a sustained discharge between the electrodes occurred.

Professor Clark observed two self-induced transparency phenomena, namely: 1) a decrease in laser pulse velocity (accompanied by laser pulse reshaping); and 2) a nonlinear transmission of pulse energy. A CO_2 laser and an ammonia gas cell were used in these experiments. Other absorbers of 10 μm radiation, primarily SF_6, have been successfully employed in self-induced transparency experiments by other researchers. However, these other absorber gases have larger heavier molecules for which the absorbing transitions are degenerate because the room-temperature Doppler profiles of the closely spaced transitions between vibration-rotation energy levels overlap. These transitions are also spatially degenerate. The effects of level degeneracy on self-induced transparency phenomena had not been completely resolved, thus, Professor Clark's experiments with a nondegenerate absorber possessing a unique transition dipole moment were performed.

The optical phenomena of self-induced transparency occurs when an intense, short light pulse travelling through an otherwise strong absorber encounters little or no actual absorption. The onset of this highly nonlinear optical process occurs when the light pulse width is shorter than the relaxation time of the medium through which it is propagating, provided the electric field intensity is large enough. Because of the potential applications of high-power Q-switched and mode-locked laser systems to transmit pulse information and radar (Lidar) signals long distances in the atmosphere, the various self-induced transparency effects

were investigated. For example, self-induced transparency could be used to great advantage to prevent high-power laser radiation from expanding ("thermal blooming") and to deliver the high-power laser radiation to the target in a narrow beam. Also, theory for certain laser pulses predicts that the laser pulse will break up into two or more pulses which would be deleterious to both information and radar (Lidar) applications.

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J. ELECTRONIC SYSTEMS: Picture Processing Using One-Dimensional Implementations of Discrete Planar Filters.

Two-dimensional filters are often used in the processing of discrete two-dimensional images. The techniques used include two-dimensional convolution, the two-dimensional fast-Fourier transform, and two-dimensional recursive filtering. The questions of stability arising in the study of two-dimensional recursive filters are not completely solved. However, the reductions in storage and computation time often make their use worthwhile. Two descriptions of planar filtering are the causal recursive two-dimensional difference equation and the two-dimensional Z transform transfer function.

The problem of implementing a two-dimensional recursive filter as a one-dimensional recursive filter was examined and significant accomplishments were made on this problem for picture processing using one-dimensional implementations of discrete planar filters by Professor J. K.

Aggarwal and other members of the Information Systems Research Laboratory of the Electronics Research Center. Their results[1,2] show that the exact one-dimensional implementation of a planar recursive filter is a time-varying filter. However, planar filters may be approximated by one-dimensional time-invariant recursive filters. The frequency response, stability, and storage requirements of the approximate filters were derived and illustrated.[1,2] Further, the work outlines a numerical example which compared the exact and approximate filtering methods. The CDC 6600 computer at The University of Texas at Austin was used for their numerical examples.

Since a large number of order functions exist, every planar filter has many one-dimensional implementations. Because there is no saving in storage or reduction in computation time when a planar filter is exactly one-dimensionally implemented, and since planar filters can not be one-dimensionally implemented with time-invariant filters, there is little reason to implement two-dimensional filters, precisely, in one-dimensional form. However, when large planar images are filtered, approximate time-invariant one-dimensional implementations require much less storage capacity than exact two-dimensional implementations. By filtering images in overlapping segments and increasing the one-dimensional filter's order, the error of approximate one-dimensional filtering can be reduced.

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K. SOLID STATE ELECTRONICS: Large Refractive Index Change by Photolysis in Lead Iodide.

Optical refractive properties of solids are exploited in opto-electronic devices utilized in optical data recording systems, integrated optical circuits, and laser-holographic display of three-dimensional images. Professor A. B. Buckman and colleagues have achieved a significant accomplishment through their experimental research on refractive index changes in lead-iodide.

The decomposition of thin PbI_2 films at temperatures above 180° C, under irradiation with an Argon ion laser light, has been well known for over ten years. In our study of the early stages of this process, under lower temperature (150-180° C) conditions, we have observed the primary effect to be a large change in the refractive index of the film, unaccompanied by any change in either film thickness or light absorption. The refractive index in the red end of the visible spectrum decreases with increasing exposure to 488 nm laser light over a range from 2.7 to 2.2 at a film temperature (during exposure) of 165° C. This is, to our knowledge, the largest reported refractive index change in any transparent, photosensitive material.

The PbI_2 films are prepared by vacuum evaporation onto glass substrates. The beam from the Ar ion laser is then defocused to a 1 cm spot size on the film, and passed through a moving diffuser to eliminate speckle before striking the film. The substrate is heated to maintain a constant, pre-selected temperature during irradiation. The film refractive index, absorption coefficient, and thickness are measured by ellipsometry before and after irradiation. The temperature (during irradiation) producing the widest controllable refractive index range is 165° C. At this temperature, the refractive index shift is approximately logarithmic with exposure, up to exposures of about 10 joule/cm^2. The incident

power density on the film was 4 mW/cm^2. Higher laser power densities cause some deviation from the logarithmic refractive index-exposure dependence. At some threshold exposure, which decreases with film temperature, the films finally become lossy, with absorption coefficients increasing rapidly with exposure above threshold.

Absorption spectra of the irradiated films, available directly from the ellipsometry data show growth and shift to shorter wavelengths, with increased exposure, of an absorption band at 570-590 nm. This band is not detectable in the nonirradiated samples. Through dispersive effects it appears to be responsible for the large refractive index shift at wavelengths greater than 600 nm.

The origin of this absorption band is thought to be the small metallic Pb agglomerates which appear as photolysis products. Two experiments give evidence that photolysis occurs at these lower temperatures. In the first, X-ray diffractometer traces, with a sole exception, are the same for both exposed and unexposed samples. The sole exception is a line at 31.4°, coincident with a line for metallic Pb, which is just resolvable out of instrument noise at exposures well below the threshold for the onset of optical absorption. In the second, annealing an exposed sample in I_2 vapor at 150° C causes disappearance of the spot where the laser exposed the film. Whether the absorption band is due to surface states at the Pb-PbI_2 interface, or to bounded-plasma resonance within the Pb agglomerates, is not yet clear from these experiments.

Details of the investigation and the significant results described above were published [(1)] in a 1975 edition of the Journal of the Optical Society of America.

Potential applications of this effect include optical data recording, fabrication of grating couplers and delineated waveguides for integrated optical circuits, and phase holography.

(I. SIGNIFICANT ACCOMPLISHMENTS)

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L. QUANTUM ELECTRONICS: Elastic Electron Scattering Amplitudes for Interpretation of Low Energy Electron Diffraction Data.

When commercial LEED (low energy electron diffraction) units became available, the amount of electron scattering data collected from a large variety of metals, alloys and other compounds increased enormously. However, except for simple structure analysis, the detailed spectra could not be evaluated and understood. The major reason for this shortcoming is the strong interaction of the slow electrons with the atoms or ions forming the lattice. This strong interaction causes the incoming electrons to scatter several times before leaving the target. The complications, introduced into the LEED data through multiple scattering, can be partially removed by dynamical averaging. The averaged Bragg peaks can be compared directly to calculated atomic scattering factors in connection with an assumed model structure.

Recently, Professor M. Fink and colleagues have made a significant accomplishment in this field by determining elastic electron scattering amplitudes which are very useful in interpreting LEED data.

Their approach was to calculate the scattering factors with the aid of a computer code involving partial wave analysis of the Dirac equation employing the most advanced atomic wave functions. During the last year they have also carried out five experiments to measure the range of the validity of their calculations. Since solids cause not only multiple scattering problems but also exhibit strong distructive and constructive features (Bragg spots), the experiments were carried out in gases. [1, 2, 3]

The results of the elastic differential cross section measurements on Ne, Ar, K, Xe, H_2, N_2, C_2H_2, C_2H_4 and C_2H_6 and a comparison with their calculations allowed the following overall conclusions: a) the calculations employing static scattering potentials agree with the experimental results within 6% in the angular range of 30° - 135°; b) at smaller angles the distortion of the atomic cloud by the incoming electron enhances the cross section significantly relative to the calculated results; and c) at very low energies this distortion is adiabatic and the scattering potential has to be modified to include an r^{-4} term. The success of this addition can be demonstrated by a comparison of their extended calculation [4] with extreme low energy data of Bederson [5] or Li.

The validity of Professor Fink's calculations and their usefulness in interpreting LEED data has been shown by numerous solid state groups. The latest application is the utilization of Fink's partial wave phase

shifts into multibeam diffraction theory. These are theoretical attempts to include multiple scattering by means of dynamical scattering theory rather than the use of averaged data and kinematic theories.

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M. ELECTRONIC COMPUTER SOFTWARE SYSTEMS: Program Proving and Strong Verification of Programs.

In a recent sequence of journal publications, Professor R. T. Yeh and colleagues have contributed significantly to the practice, art, and science of electronic computer software systems. Professor Yeh's significant accomplishments include contributions to periodicity of sequential machines,[1] marker automata,[2] formal languages automata and development,[3, 4] and strong verification of programs.[5]

(I. SIGNIFICANT ACCOMPLISHMENTS)

Professor Yeh's forthcoming article[5] in the IEEE Transactions on Software Engineering develops a method of program proving. Traditional methods of program proving usually involve two parts, one for proving the partial correctness and the other for proving termination. Yeh's research is directed toward developing methods for a single, combined, approach to program proving.

Given a program at whose output a certain predicate must be shown to be true, the traditional scheme associates predicates (assertions) at each point of the program. These assertions are shown to be true every time the program reaches the corresponding point, using induction (starting from the input assertion). Termination is then proven separately by showing that successive iterations decrease a certain function value on a well-founded set, which by definition must have a least element.

The current scheme developed by us may be characterized as an inverted approach. Given the output assertion, we attempt to generate the weakest input assertion which would imply termination and the output assertion. If the given input conditions imply this weakest input assertion, the program has then been shown to be correct. Note the absence of a separate proof for termination.

The scheme for generating the weakest precondition (input assertion) from the post condition (output assertion) is straightforward in the absence of loops (in which case termination proof is trivial).

(I. SIGNIFICANT ACCOMPLISHMENTS)

We show that for a loop of the form While B do S, the weakest precondition satisfies a certain recursive equation. (One advantage of this recursive equation is that the conjectures regarding the weakest preconditions may be readily verified.) Clearly there are many solutions to this recursive equation. We show that

(i) the least solution P* to this recursive equation is the condition, i.e., if P is any other solution that P* = P,

(ii) the program does not terminate when input with elements from P -P*,

and (iii) any solution P is a loop invariant.

Partial correctness proofs using inductive assertion may now be interpreted as locating a solution P to the recursive equation, which serves as a loop invariant. Then termination has to be proven separately. However, if we show that the input assertions imply P* (the least solution) then both correctness and terminations are automatically proven.

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N. QUANTUM ELECTRONICS: Third Harmonic Generation in SF_6 at 10.6 Microns.

Nonlinear optical devices provide a means by which mixers, upconverters and downconverters, and harmonic generators may be realized at optical frequencies for communication application. Professor Michael F. Becker and colleagues have achieved a significant accomplishment through their experimental research on third harmonic generation produced by carbon-dioxide (CO_2) laser radiation in sulphur-hexaflouride (SF_6) gas.

(I. SIGNIFICANT ACCOMPLISHMENTS)

Both nonphase-matched and phase-matched optical third harmonic generation (THG) have been observed in our laboratory. Molecular vibrational-rotational resonances enhanced the nonlinear conversion process. This is one of the first observations of a nonlinear optical interaction due to vibrational nonlinearities in molecules and the first thorough theoretical treatment of a molecular nonlinear system. Although THG produced by CO_2 laser radiation has been observed in several crystals, the use of a gaseous nonlinear medium may produce more satisfactory results because of the difficulties in crystal phase-matching, crystal growth for large interaction volume, and optical damage, which limit efficient conversion.

In phase-matched THG we observed conversion efficiencies of up to 10^{-10} for 270 nsec, 120 mj pulses at 10.6 microns. Phase matching was achieved with both methylene chloride (CH_2Cl_2) and chloroform ($CHCl_3$). Phase matching occurred for 10-20 torr of SF_6 pressure at mixing ratios between 1:1 and 10:1, buffer gas to SF_6, depending on the buffer gas and the focusing parameter. The results of the phase-matching experiments were in exact agreement with theory. We also found that for power densities of greater than 100 Mw/cm^2 the nonlinear susceptibility was strongly saturated and conversion efficiencies were reduced by up to five orders of magnitude from the theoretically expected values.

We conclude that for most efficient conversion lower energy densities must be used, and that the utilization of shorter pulses will result in the

best conversion efficiencies. For example, 1 nsec pulses greater than 100 mj from a mode-locked CO_2 laser might be converted to the third harmonic at between 10^{-2} and 10^{-4} efficiency because of reduced saturation of the nonlinear coefficient.

Details of the investigation and the significant results described above were presented during 1975 and 1976 at two important conferences

May 6-7, 1975 — DoD JSEP TOPICAL REVIEW ON "ADVANCES IN RADIATION TECHNOLOGY" at Massachusetts Institute of Technology

"Nonlinear Optics in the Far Infrared Utilizing Molecular Vibrational Effects" by M. F. Becker,

and

June 14-18, 1976 — IX INTERNATIONAL QUANTUM ELECTRONICS CONFERENCE, Amsterdam, The Netherlands

"Third Harmonic Generation in SF_6 at 10.6 Microns" by M. F. Becker, M. H. Kang, and K. M. Chung,

and were published in a 1976 edition of the Journal of Applied Physics

M. H. Kang, K. M. Chung, and M. F. Becker, "Third harmonic generation in SF_6 at 10.6 μ," Journal of Applied Physics, Vol. 47, 1976, pp. 4944-4948.

Potential applications for this effect include optical frequency upconverters, downconverters, and harmonic generators at infrared wavelengths.

(I. SIGNIFICANT ACCOMPLISHMENTS)

O. ACOUSTICS AND RADIO SCIENCE: Magnetotelluric and Dipole-Dipole Soundings in Northern Wisconsin (Technical Liaison with U.S. Navy Projects Sanguine/Seafarer).

Long-range communication to nuclear submarines submerged in distant oceans from on-shore U.S. sites is dependent upon the electrical resistivities of the earth's crusts. Professors H. W. Smith and F. X. Bostick, and their colleagues have contributed significant accomplishments through their basic radio science research, magnetotelluric instrumentation development, field work on magnetotelluric and dipole-dipole soundings at various sites including Northern Wisconsin, and on their computerized data processing techniques. The U.S. Navy Projects Sanguine and Seafarer are vitally interested in methods of measuring electrical conductivity values of the earth through a region for site selection purposes, as well as methods for determining the patterns of horizontal electric dipole antennas situated at the ground surface. Over the past three years the Smith-Bostick research group has developed methods based on audio-magnetotelluric measurements which are demonstrated to yield excellent results for both objectives.

From their extensive work and findings, this significant accomplishments report selectively emphasizes "MAGNETOTELLURIC AND DIPOLE-DIPOLE SOUNDINGS IN NORTHERN WISCONSIN" which they have recently presented at meetings and conferences, and which is expected to appear in print in a forthcoming edition of the Geophysical Monograph Series of the American Geophysical Union.

(I. SIGNIFICANT ACCOMPLISHMENTS)

ABSTRACT

D-C Dipole-Dipole measurements were made at 21 sites in Northern Wisconsin along three radial lines from the 22 Km North-South and East-West Wisconsin Test Facility antennas used for the study. The South-East radial was considered to be the most favorable for detecting the highest resistivity formations and their thicknesses, which were the principal objectives of the Joint Deep Crustal Resistivity Study. The highly conductive Flambeau Anomaly was found to cross this South-East radial near the Flambeau River resulting in a drastic decrease in signal level. As a consequence, the measured apparent resistivities as a function of separation were altered to the extent that the quantitative results are misleading. Magnetotelluric (MT) measurements were made at all but two of the dipole-dipole sites in a frequency range from about 0.03 to 800 Hz in 13 selected bands. MT results are shown for six sites, two of which show the effects of the Flambeau Anomaly and four highly resistive sites to the South-East of it. Average thickness of the high resistivity layer is estimated to be between 15 and 20 Km with near surface S values of 0.2 to 0.5.

Details of their investigations and the significant results described above were presented to key workers and Department of Defense officials during 1976 at two meetings and conferences:

(I. SIGNIFICANT ACCOMPLISHMENTS)

March 9, 1976 — THIRTEENTH ANNUAL ELECTRONICS RESEARCH REVIEW (DoD JSEP)
The University of Texas at Austin

"Transmitting Antenna Performance Evaluations for Project Sanguine/Seafarer Site Surveys Using Magnetotelluric Tensor Impedance Measurements"
presented by
F. X. Bostick and H. W. Smith

August 2-4, 1976 — OFFICE OF NAVAL RESEARCH & COLORADO SCHOOL OF MINES SYMPOSIUM ON "THE NATURE AND PHYSICAL PROPERTIES OF THE EARTH'S CRUST," Vail, Colorado

"Magnetotelluric and Dipole-Dipole Soundings in Northern Wisconsin"
presented by
H. W. Smith and F. X. Bostick

and are expected to appear in a forthcoming monograph published as

F. X. Bostick, H. W. Smith, and J. E. Boehl, "Magnetotelluric and Dipole-Dipole Soundings in Northern Wisconsin," Geophysical Monograph Series on "The Nature and Physical Properties of the Earth's Crust," American Geophysical Union. (Preprints of the publication are available upon request.)

Another measure of the significance of the research techniques and instrumentation developed by Professors Smith and Bostick is that the AMT methods and the latest equipment have been used in field measurements for projects Sanguine/Seafarer by research personnel from the Naval Underwater Systems Center (NUSC) during the period September 1, 1975, through April 1, 1976.

(I. SIGNIFICANT ACCOMPLISHMENTS)

The initial phase of this project consisted of a training period for NUSC personnel in the operation of the system at selected sites in the vicinity of Austin, Texas. Within about 70 miles of the University a range of near-subsurface resistivities from 2 to 20,000 ohm-meters is available for test sites. This range of resistivities is as broad as is likely to be encountered anywhere in the U.S., and the experience gained by NUSC proved to be valuable in their later field measurement program.

Our research group made certain modifications of the equipment to meet the specific needs of the project and developed the software for the initial processing of the AMT data in the field with the aid of a programmable calculator. The process has been automated to the point where estimates of tensor resistivities, phases, and coherencies are computed and printed out for each run in a matter of a few minutes. Thus repeat runs can be compared and on-site decisions relative to site selections can be made. This equipment and capability are unique and have proven to be invaluable in field measurements programs of this type.

The NUSC program included the measurement of the antenna pattern of the Sanguine Test Facility in Wisconsin, site measurements at the Nevada Test Site for Project Seafarer, and additional test measurements in the vicinity of the NUSC facility. This research group has acted as consultants for the NUSC project and has made trips to the Wisconsin and Nevada sites to correct problems which were experienced in the operation of the system.

(I. SIGNIFICANT ACCOMPLISHMENTS)

This group is continuing to aid NUSC in the analysis and interpretation of the results of this measurement program.

P. INFORMATION SYSTEMS: Distribution-Free Performance Bounds in Error Estimation.

In a recent sequence of journal publications, Professor T. J. Wagner and colleagues have contributed significantly to information systems for the difficult task of pattern recognition.

One of the basic mathematical models finding widespread use in pattern recognition problems is the following. A statistician observes a random vector X and wishes to estimate its state θ taking the values $1, \ldots, M$. His only knowledge of the probability distribution of (X, θ) is that contained in his data, a sample of size n drawn from the distribution of (X, θ). Generally he would like an estimate of θ, based on X and his data, to have a probability of error close to that which could be attained if the distribution of (X, θ) were known. Indeed much of the earlier investigation for this problem has been concerned with finding estimates for which the probability of error approaches, in some probabilistic sense, the smallest possible probability of error as the sample size n tends to infinity.

While such asymptotic results are reassuring to the statistician they nevertheless fall short of helping him in the finite sample case. If his estimate of θ yields a probability of error L_n, which is unknown to him because he doesn't know the distribution of (X, θ), then his first finite sample considerations are estimating L_n from the data and knowing how much confidence he can place in the estimate. In particular, if $\hat{L}_n$ represents an estimate of L_n from the data, the statistician would like to know $P[|\hat{L}_n - L_n| \leq \epsilon]$ for $\epsilon > 0$. Once again, lack of knowledge of the distribution of (X, θ) prevents a calculation. The only thing then

that can be done is to try to find lower bounds for $P[|\hat{L}_n - L_n| \leq \epsilon]$ (or, equivalently, upper bounds for $P[|\hat{L}_n - L_n| \geq \epsilon]$) which, to be useful must not involve <u>any</u> characteristic of the unknown distribution of (X, θ) and, for a fixed $\epsilon > 0$, must tend to 0 with n.

Wagner and Rogers first studied the finite sample problem in [1]. For a class of estimates of θ, called local estimates, they found a natural estimate of L_n which had

$$P[|\hat{L}_n - L_n| \geq \epsilon] \leq A/n\epsilon^2.$$

Here, A is an explicitly given small constant depending only on M and the number of nearest neighbors used in the local estimate of θ. Wagner and Devroye [2], constraining the estimates of θ to come from linear partitions of the range of X, showed that a particularly simple estimate of L_n had

$$P[|\hat{L}_n - L_n|] \leq An^d e^{-Bn}$$

where d is the dimension of the range of X, and A and B are explicitly given constants depending only on M, d and ϵ. This later result appears to be a substantial addition to the vast literature on linear discrimination functions.

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